MACROPOROUS SILICON DEEP UV FILTERS

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Outline

- Introduction and Rationale
- Physical basis of filtering in Macroporous silicon membranes
- Macroporous Silicon chemistry and fabrication
- Brief process flow diagram
- ALD coating description
- Experimental results
- Conclusions
- IR and other applications

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Existing technology

ABSORPTION-BASED

- Not suitable for deep UV range
- Available materials absorb across entire deep UV spectrum

INTERFERENCE-BASED

- Limited width of the rejection bands;
- Poor physical longevity and lack of environmental stability (deep UV filters)
- Strong angular dependence of the pass band or rejection edge position

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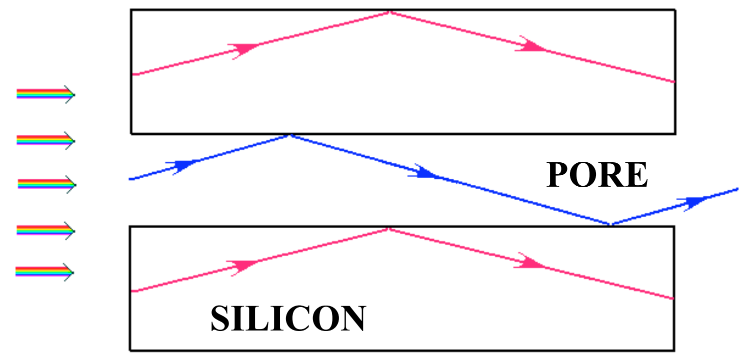
Transmission mechanism through an uncoated MPSi array

- Up to 700-900nm- transmission through the pore leaky waveguide array
- From 700-900nm to ~5Λ – transmission through the Si host waveguide array
- 5Λ and above- transmission through an "effective medium"

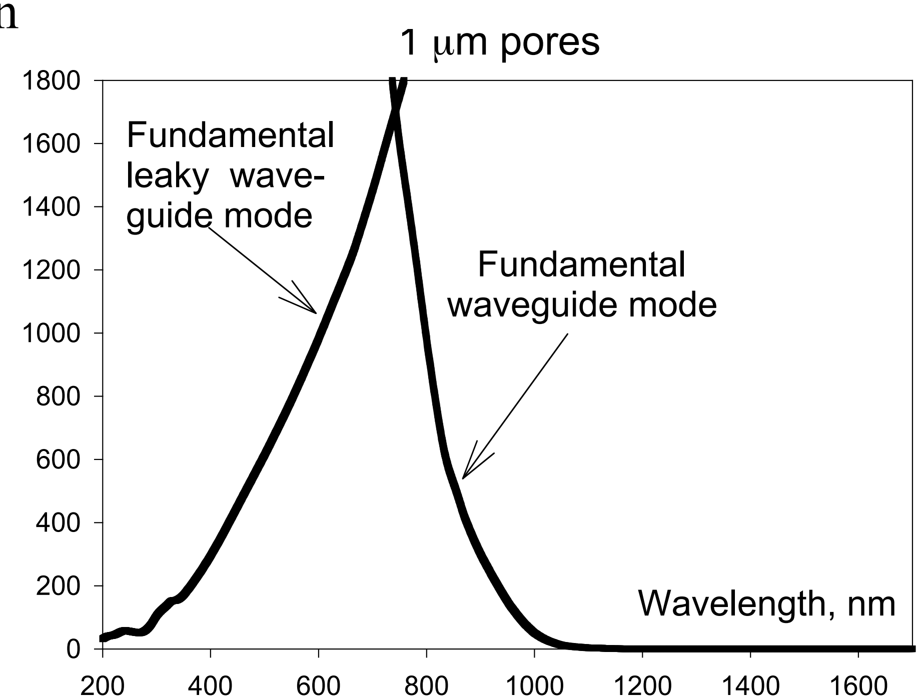


UV-visible range:

$$\alpha = f_0 \lambda^2 / d^3$$

$f_0 \approx 0.09$ index factor

$$\lambda_{-3dB} = \sqrt{\ln(2) \cdot \frac{d^3}{f_0 \cdot L}} \qquad \lambda_{-20dB} = \sqrt{\ln(100) \cdot \frac{d^3}{f_0 \cdot L}}$$



Sharpness and position of the rejection edge are bounded!

Formulas taken from [I. Avrutsky and V. Kochergin, *Appl. Phys. Lett.*, 82, 3590 (2003)]

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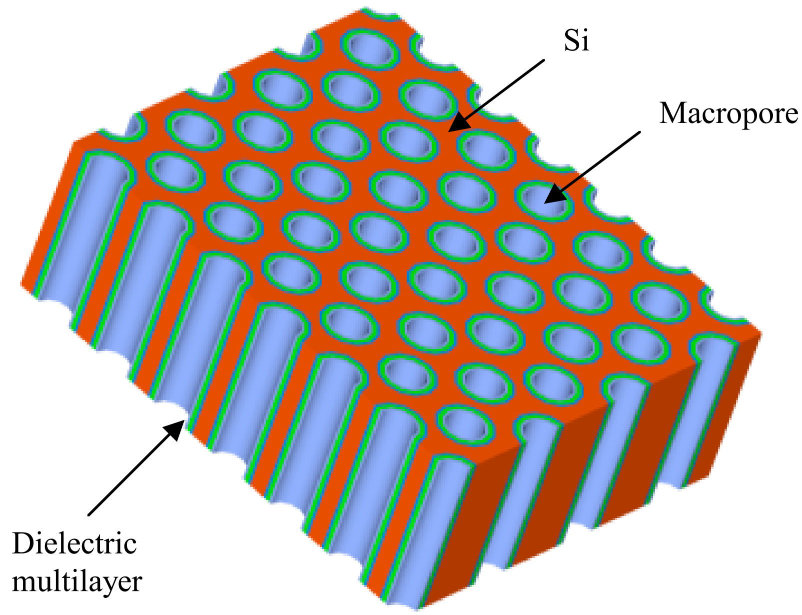
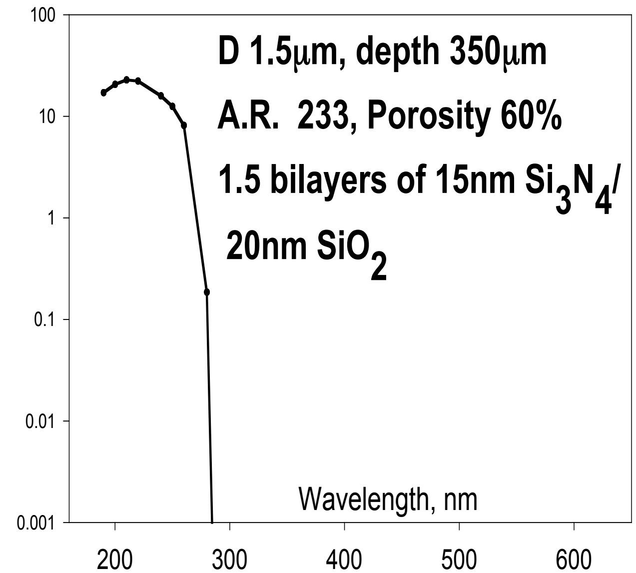
Coated MPSi arrays

- Leaky mode losses can be selectively adjusted.
- High rejection levels are predicted.
- Transmission down to far and extreme UV is possible.
- Spectral position and shape of pass- and rejection bands are independent on angle of incidence.
- Far fewer layers are necessary in order to achieve a comparable edge sharpness and rejection level than in common interference filters.
- Filters are much more environmentally and thermally stable.





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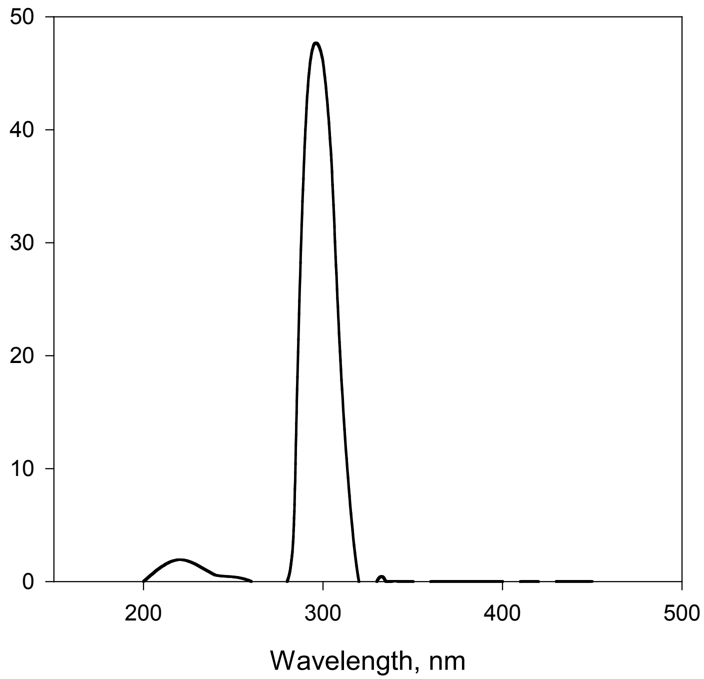
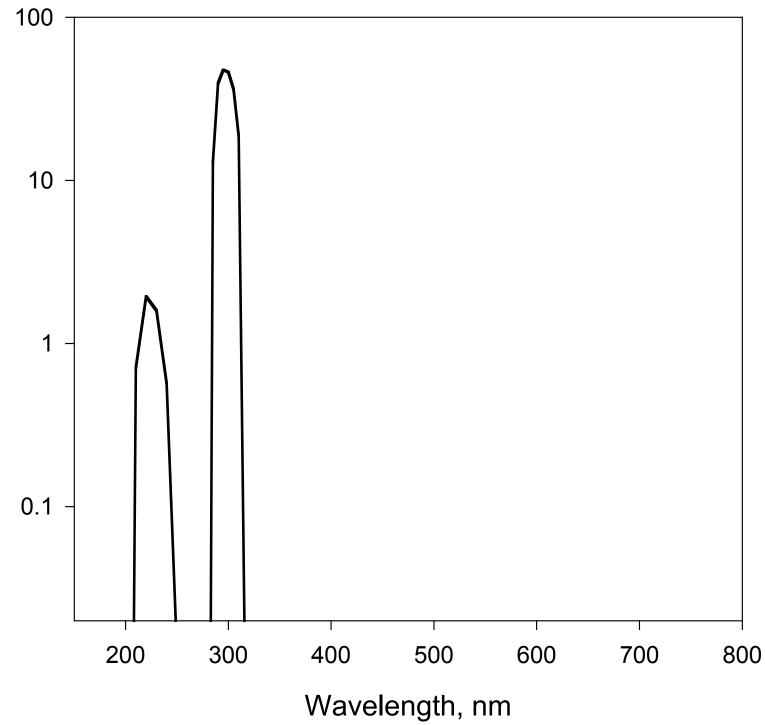
Design (narrow bandpass filter)



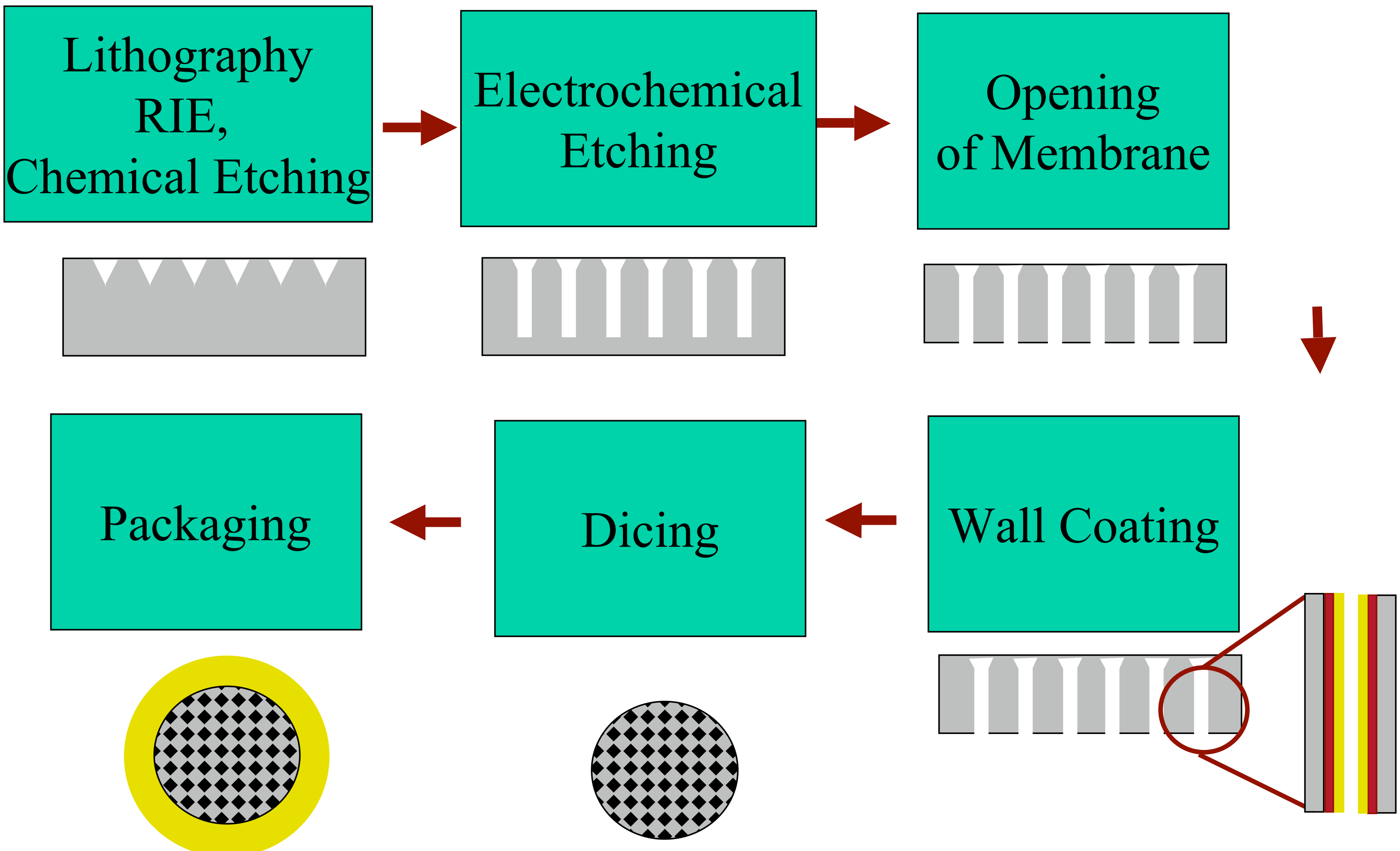
a)



b)

Numerically calculated spectral dependences of the transmission through an MPSi membrane with a 19-layer pore wall coating designed as a narrow bandpass filter, with band centered at 300nm. The transmission in a) is plotted on a linear scale, while in b) is given on a logarithmic scale.

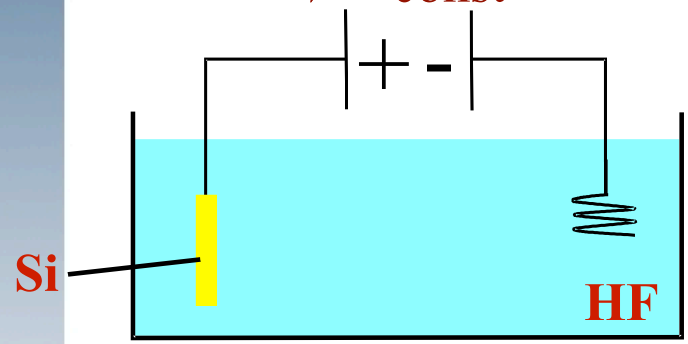
Process flow

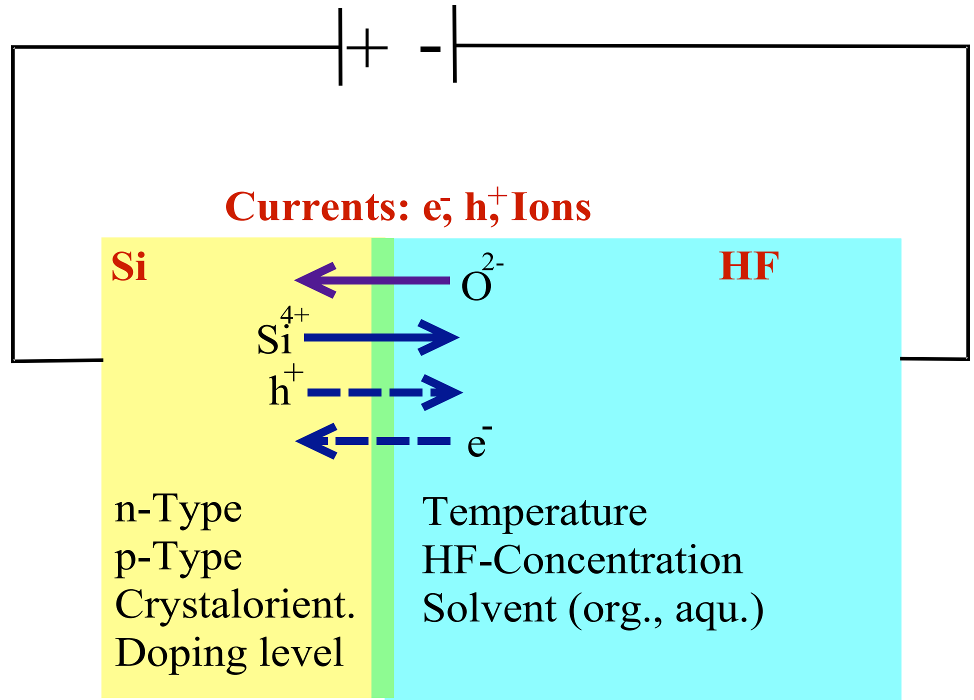


Porous silicon etching

$j = \text{const}$

$V = \text{const}$





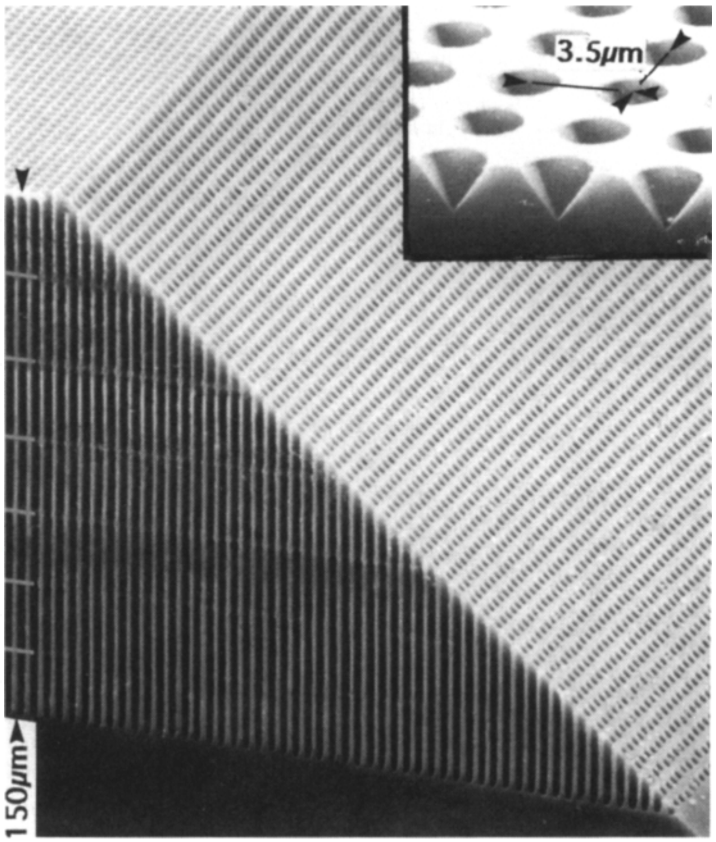
Interface:

- Porous Silicon
- (Electropolishing can occur)

n-Si: Current limitation by hole supply
Illumination of the silicon is necessary.

Porous silicon etching (continuation)

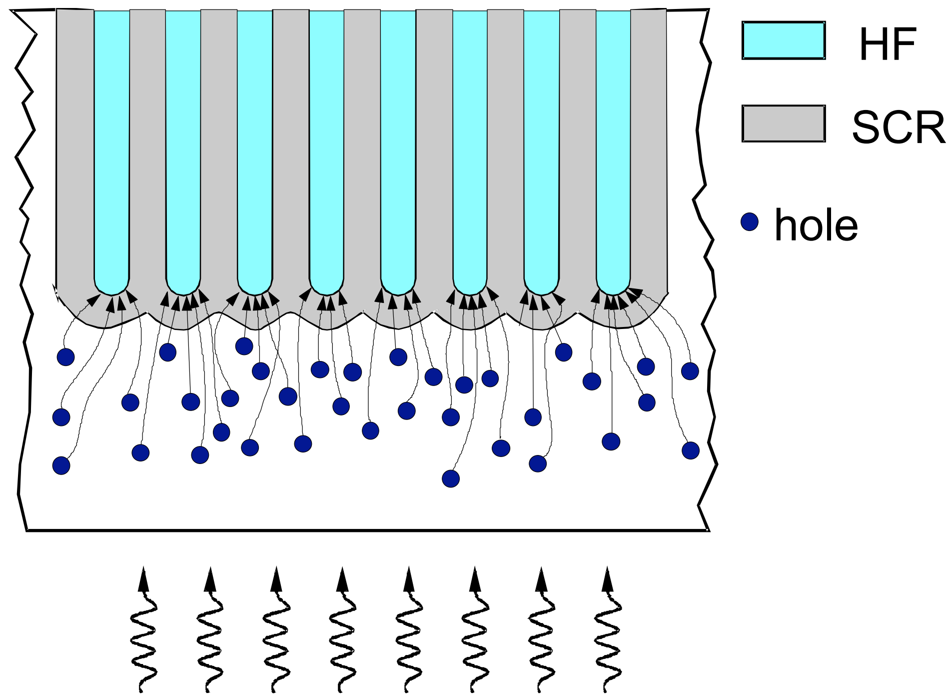
V. Lehmann, H. Föll,
J. Electrochem. Soc., 137, 653 (1990)



V. Lehmann, *J. Electrochem. Soc.,* 140, 2836 (1994)

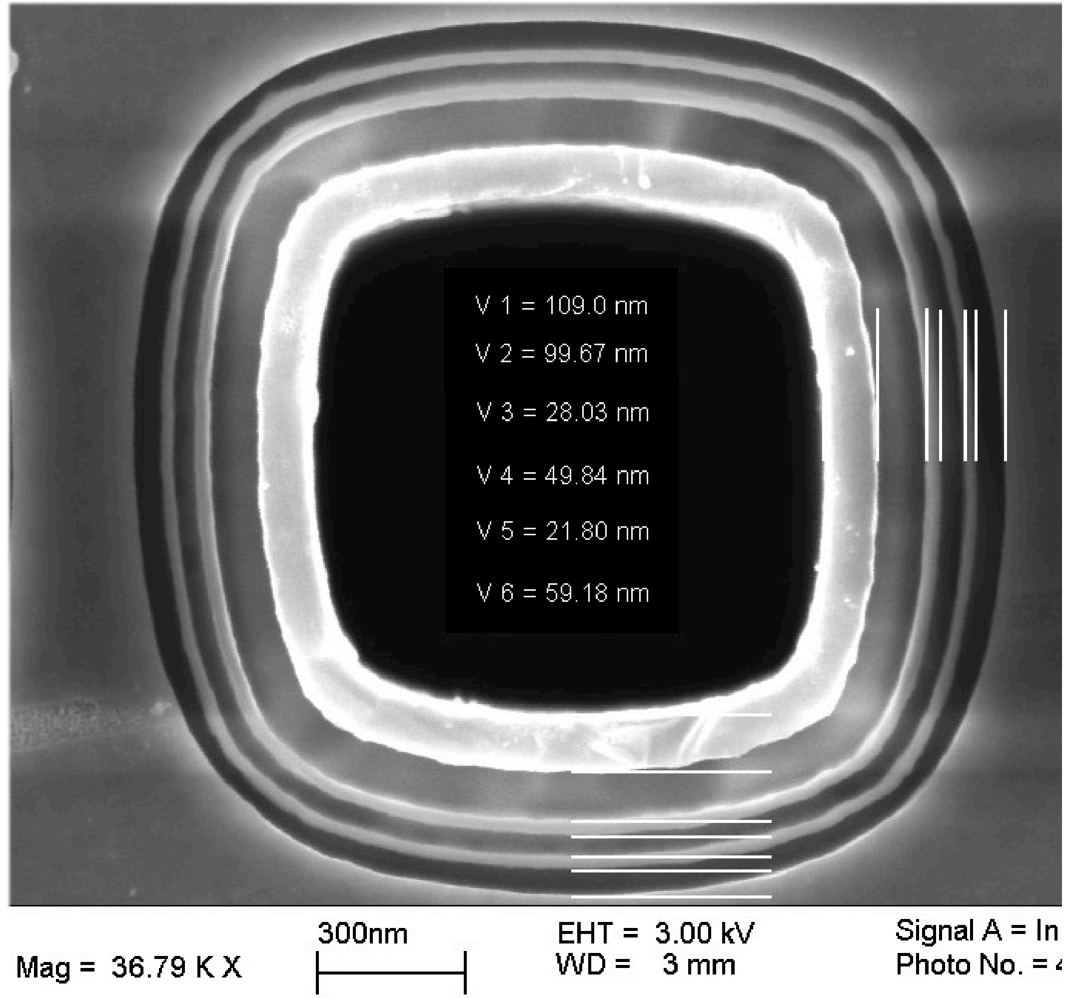
Macropores in silicon

- space charge region around macropores
- photo (or electrical) generation of holes
- holes are minority carriers



Multilayer coating of the pore walls (LPCVD)

Coating of MPSi structure is demonstrated



- Coating is not uniform
- High stresses
- Very limited choice of materials

LPCVD pore wall coating and SEM images done by MEMS PI. www.memspi.com

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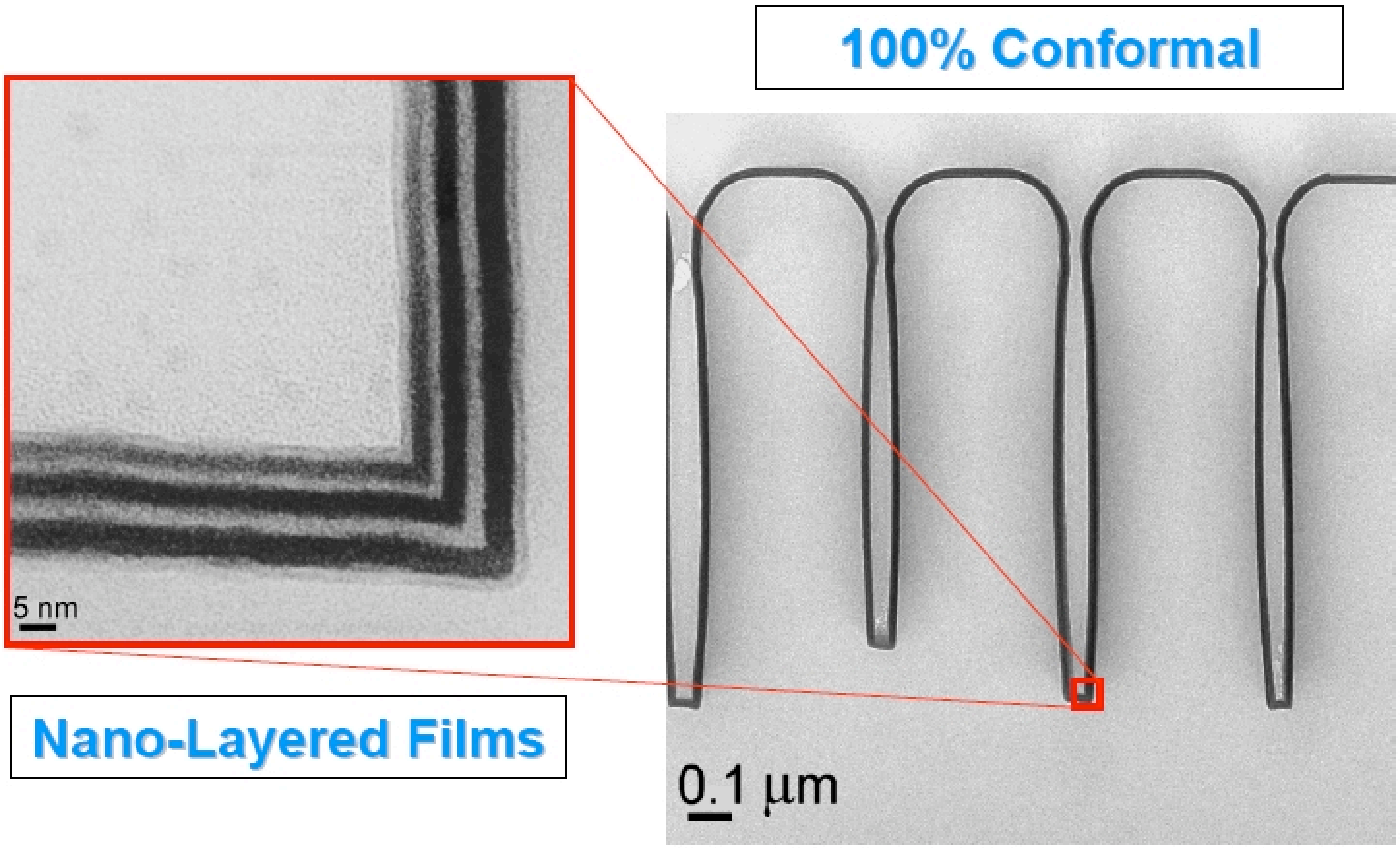
Atomic layer deposition (ALD)

ALD - Atomic Level Precision - 100% Conformal Films



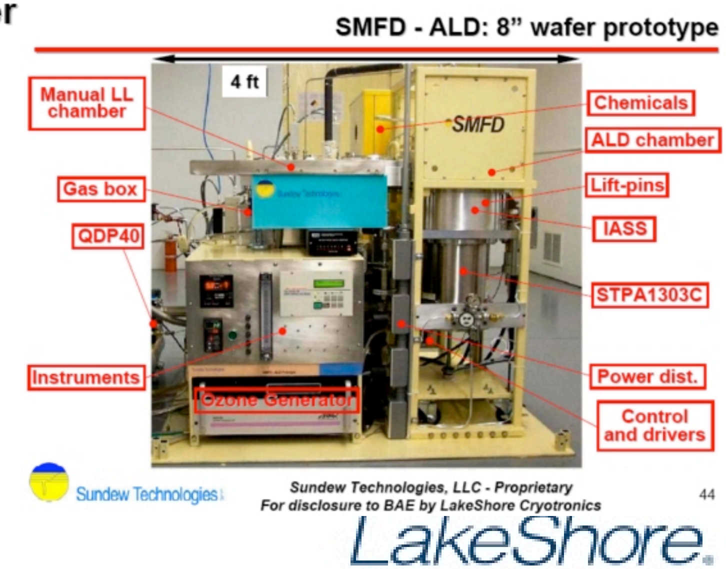
Ofer Sneh et al., Thin Solid Films 402 (2002) 248

ALD (continuation)

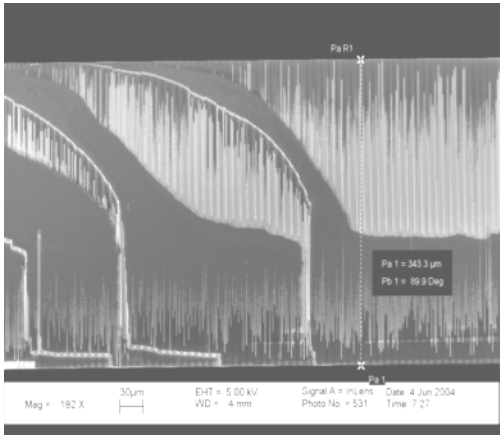
ALD - Atomic Level Precision - 100% Conformal Films

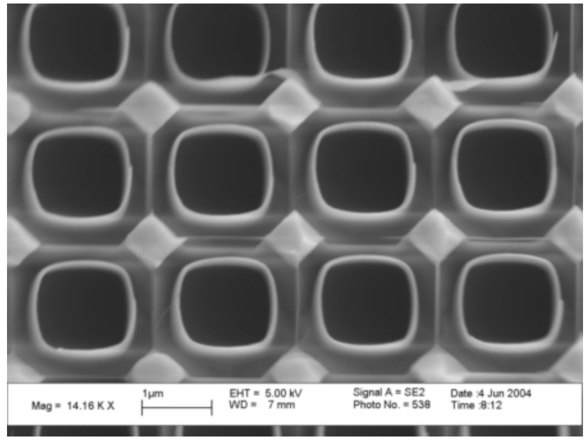
- ALD is inherently 100% conformal
- The key is the layer-by-layer growth
- Transport time into high aspect ratio structures is fast (~100 msec/mm)
- The challenge is - chemical delivery. For example, 8" DRAM wafer (70 nm generation) requires 6×10^{18} precursor molecules per dose !!!
- An Ultra High Area (UHA) substrate such as a porous silicon membrane requires 6×10^{19} precursor molecules per dose !!! ⇒ 87 grams of trimethylaluminum per 1 μm of film! ($50 per technical grade precursor)

Several dozens of different coatings (metals, semiconductor and dielectrics) have been demonstrated



Coating uniformity





Good quality layers (granular structure was not observed)

Better than 5% for Al_2O_3

82nm

HfO_2 trials were not successful

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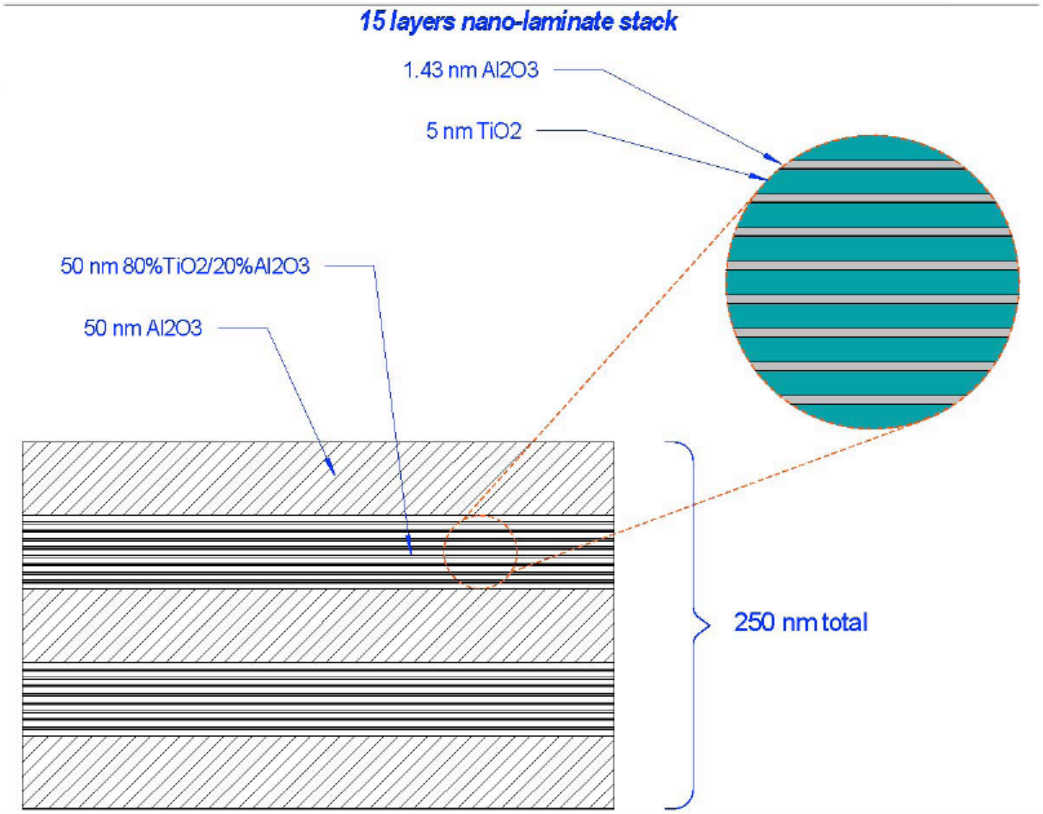
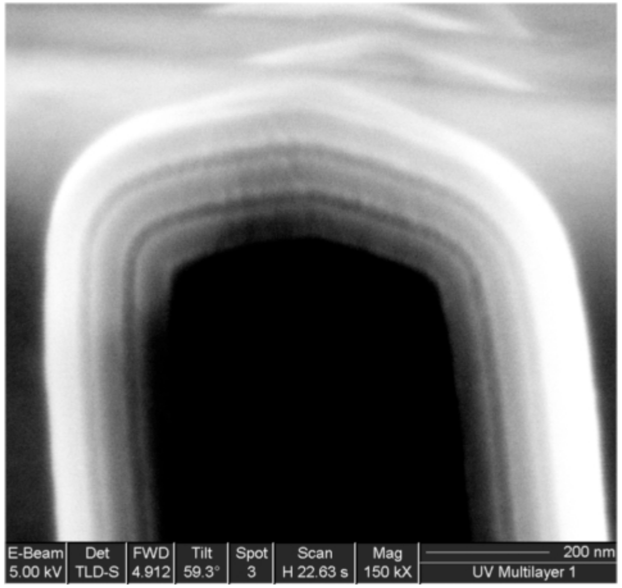
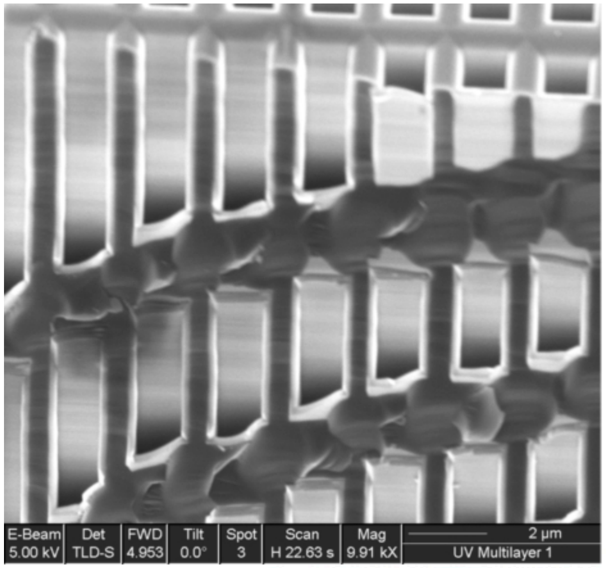
Nanolaminated stacks and refractive index engineering







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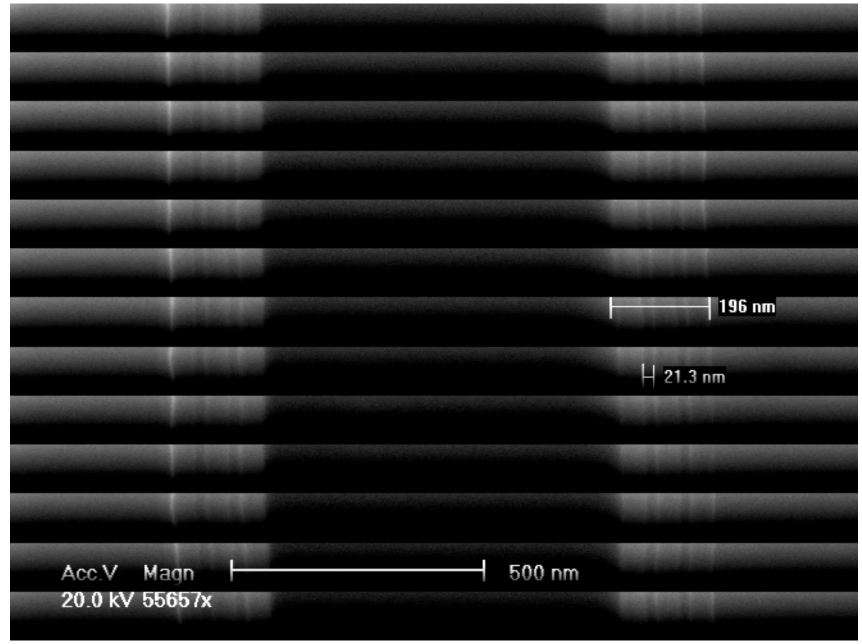
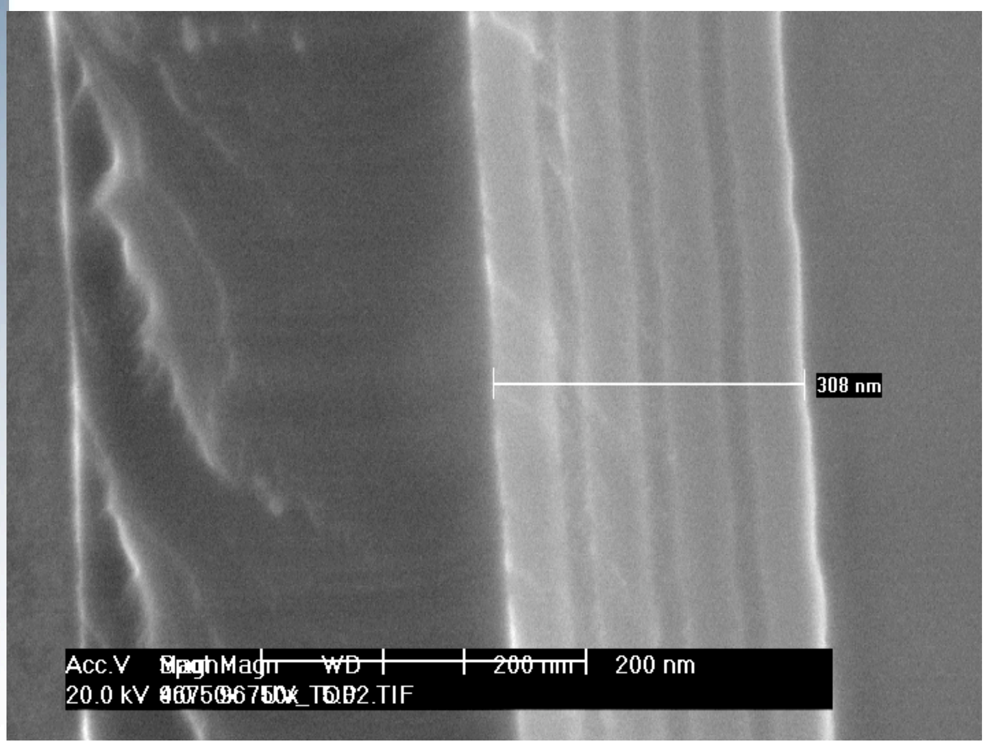
5-layer TiO2/Al2O3 ALD coating (ALD)





7-layer TiO2/Al2O3 ALD coating (ALD)

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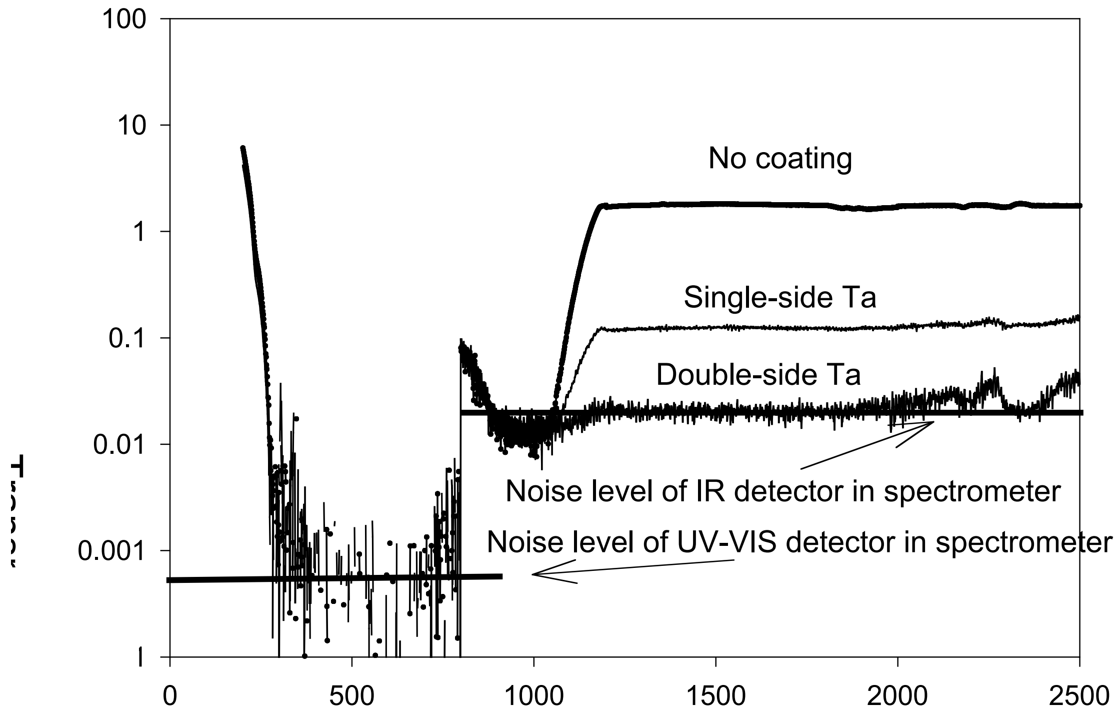
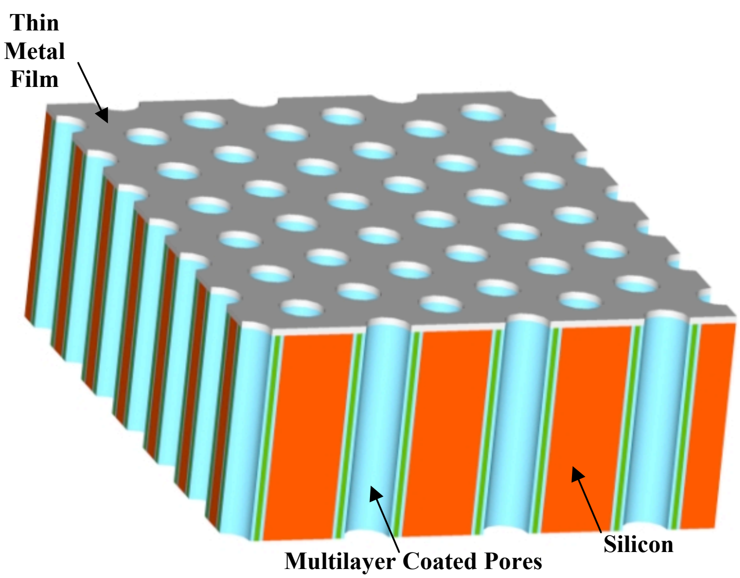
Wide blocking, higher than 5 OD





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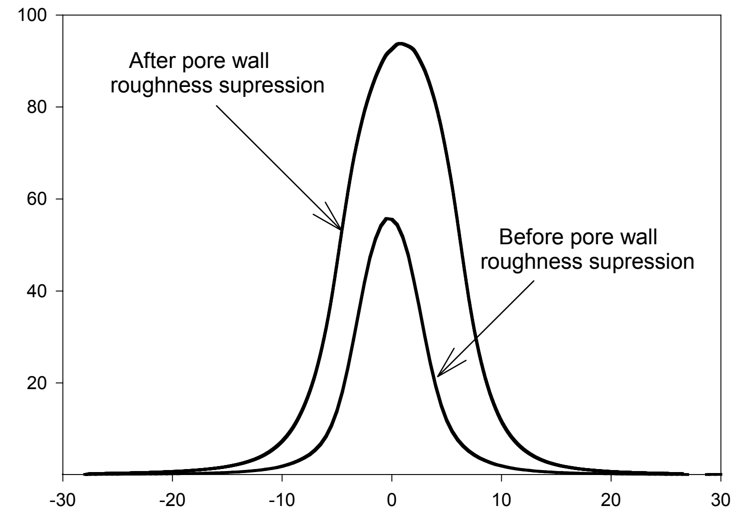
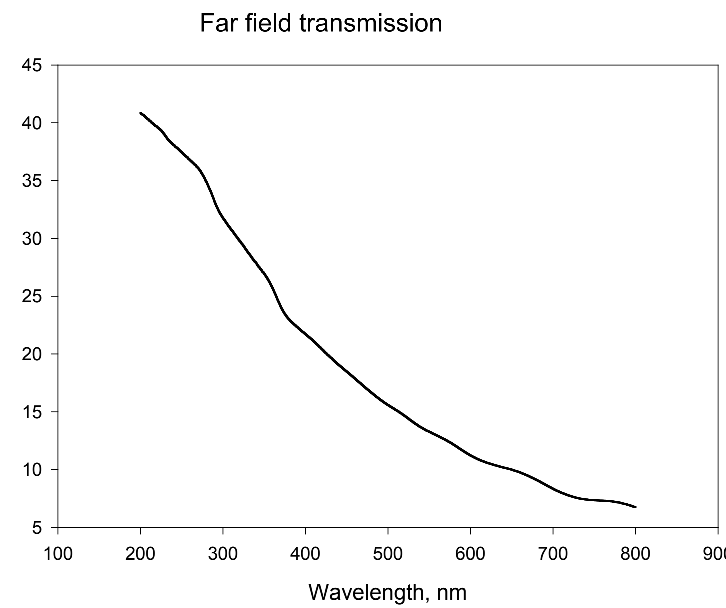
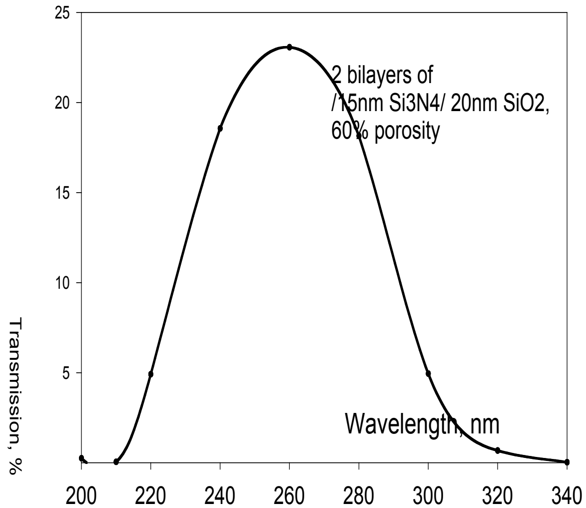
Near field transmission efficiency exceeds 50% within the pass band

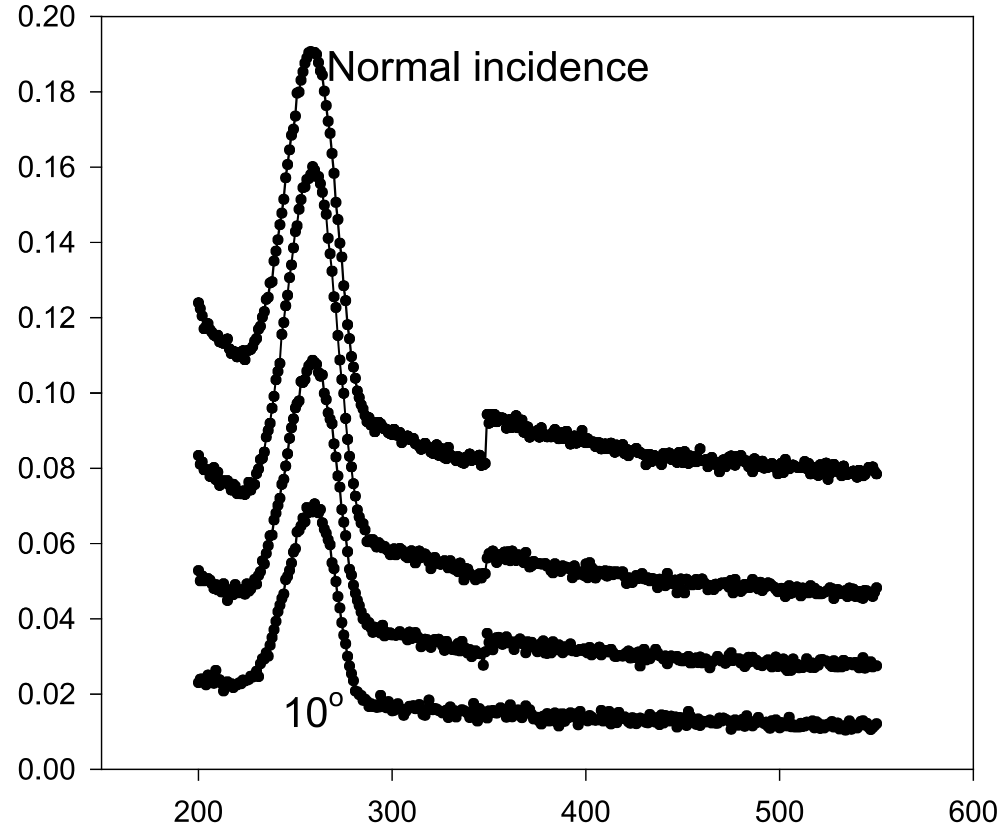


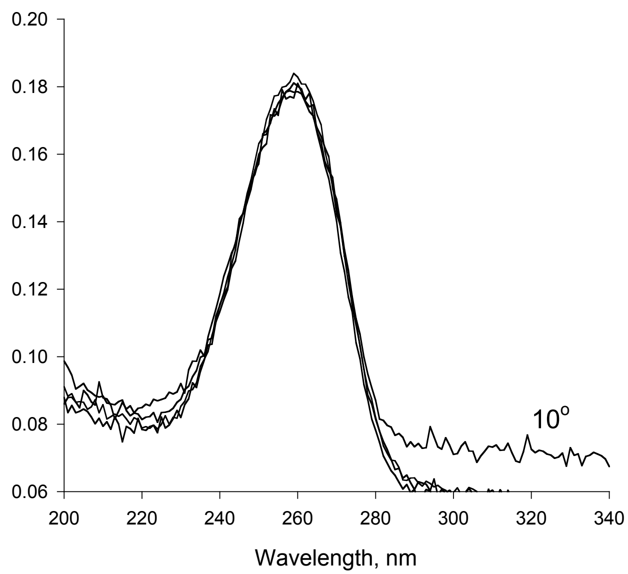
Far field transmission efficiency exceeds 30% within the pass band



Optical testing of MPSi layer with multilayer coating





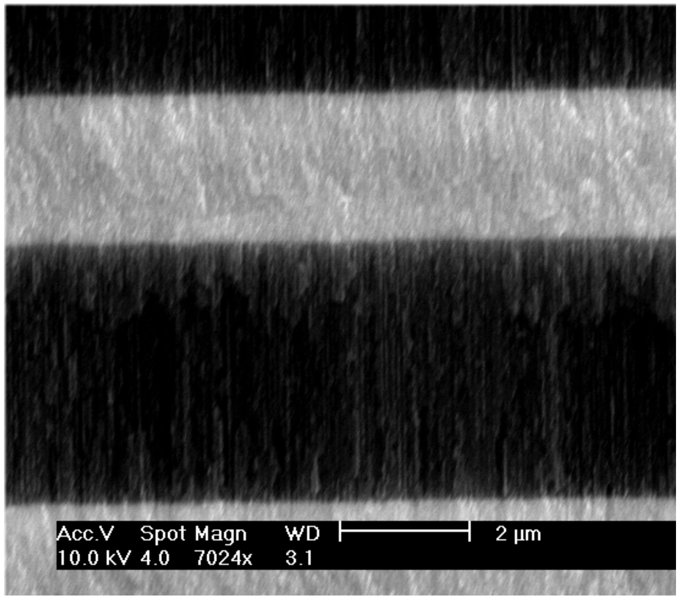


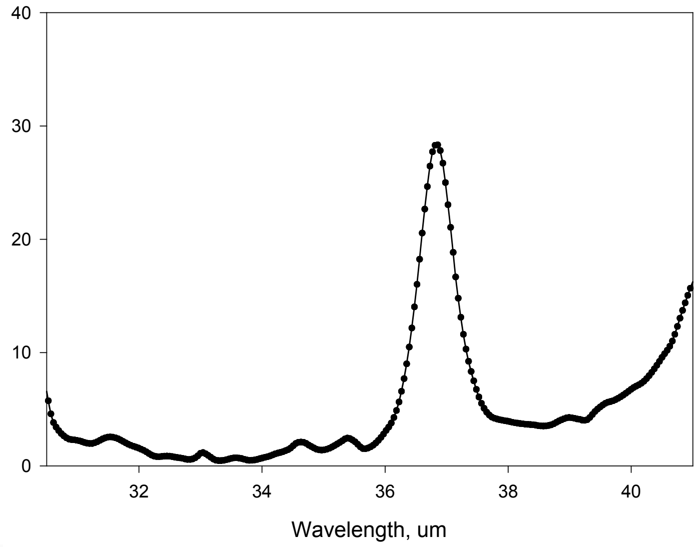
Conclusions

- Pore formation process meet the requirements.
- Feasibility of ALD pore wall coating is demonstrated for Al2O3 single layer and a Al_2O_3/TiO_2 nanolaminated stack. Attempts at HfO_2 deposition have failed so far. No functional filter fabricated.
- Good agreement between theory and experiment. Good understanding of what's happening and what needs to be done.
- For further progress, an ALD machine <u>at Lake Shore</u> is required .

IR porous mesoporous silicon filters and mirrors

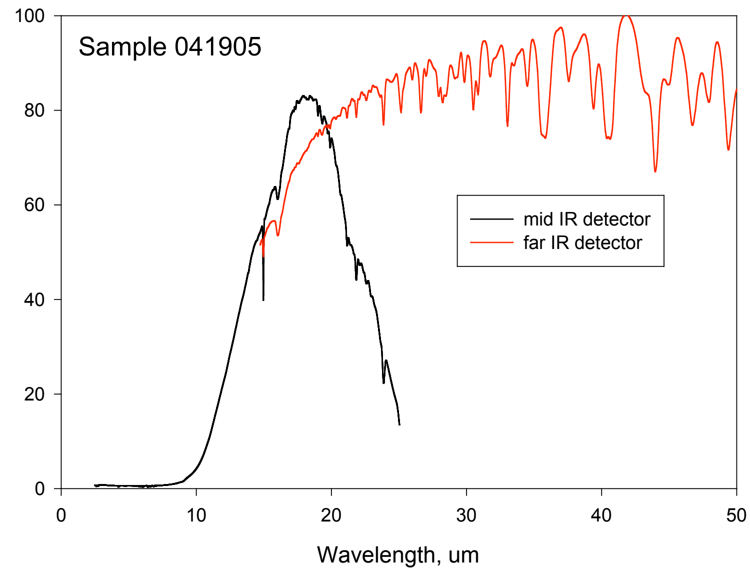
Consist of a porous silicon multilayer composed of alternated high-porosity/low porosity layers.

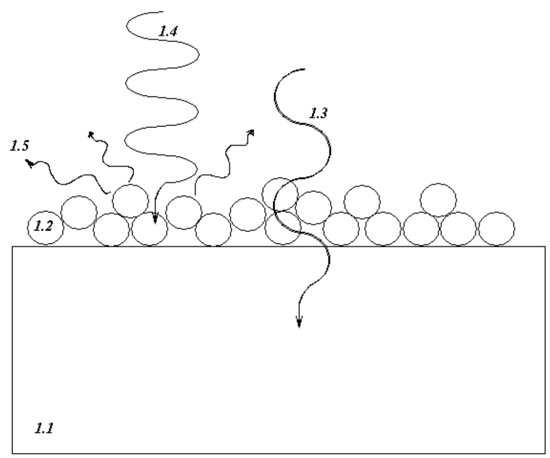




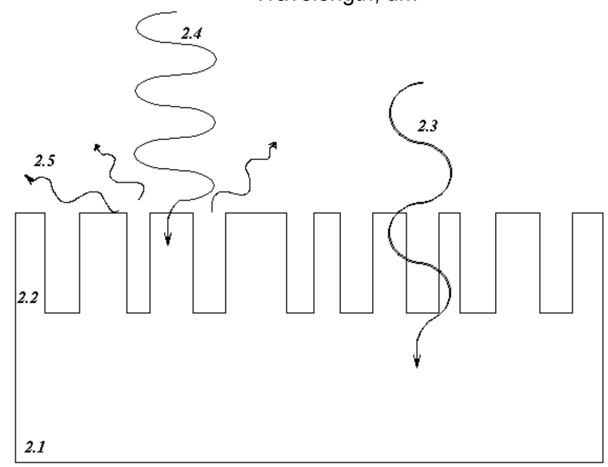
IR long wave pass filters

•Random MPSi layers
•Light <u>scattering</u> is the key
•Used as a part of almost any band-pass filter





Scattering by applied particles



Scattering by random pores

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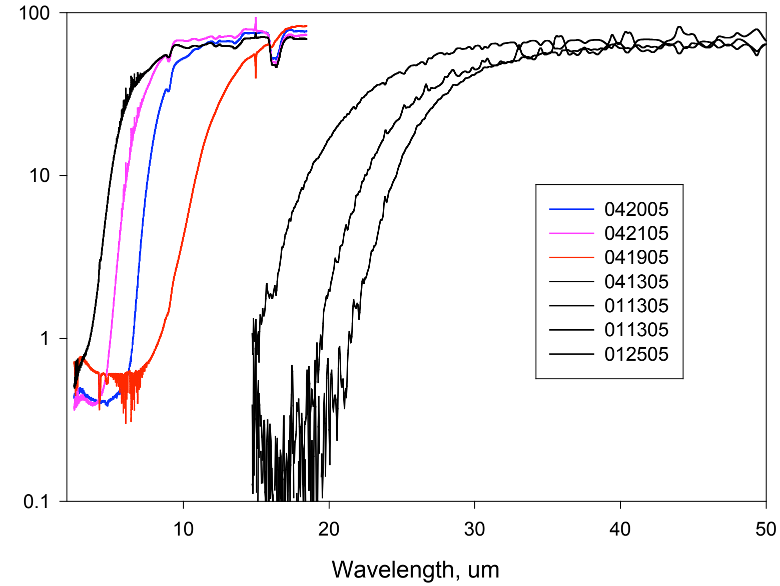
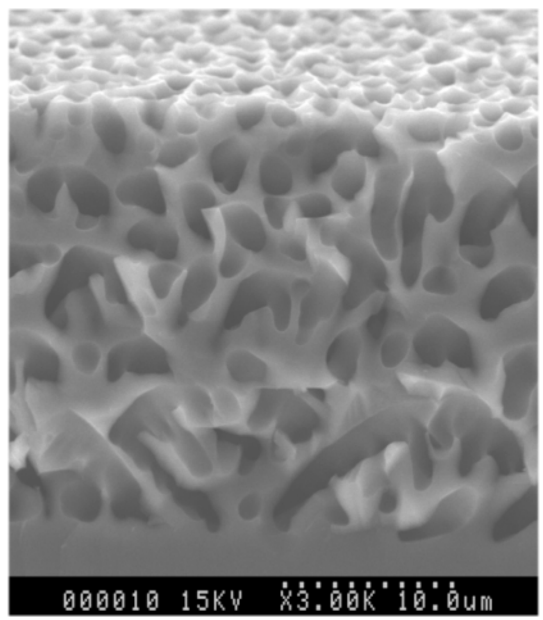
IR long wave pass filters (continuation)

Glancing angle reflection, 100mm wafer



Normal to wafer surface



Pore layer cross section

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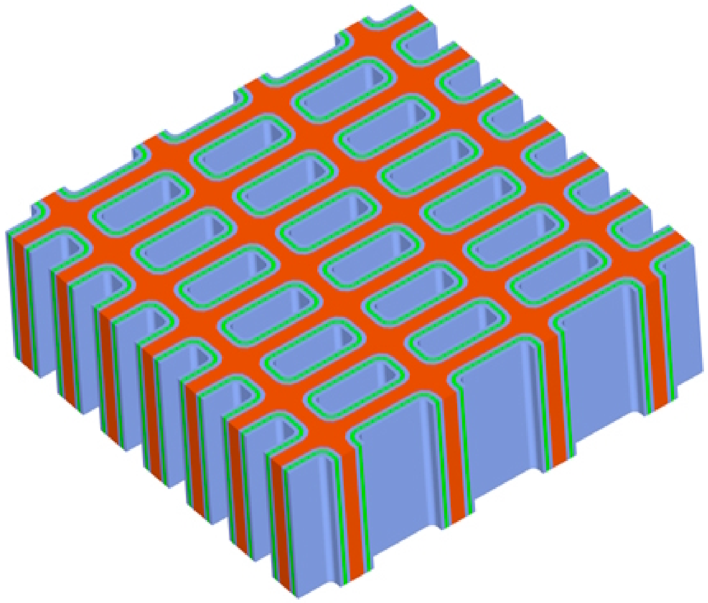
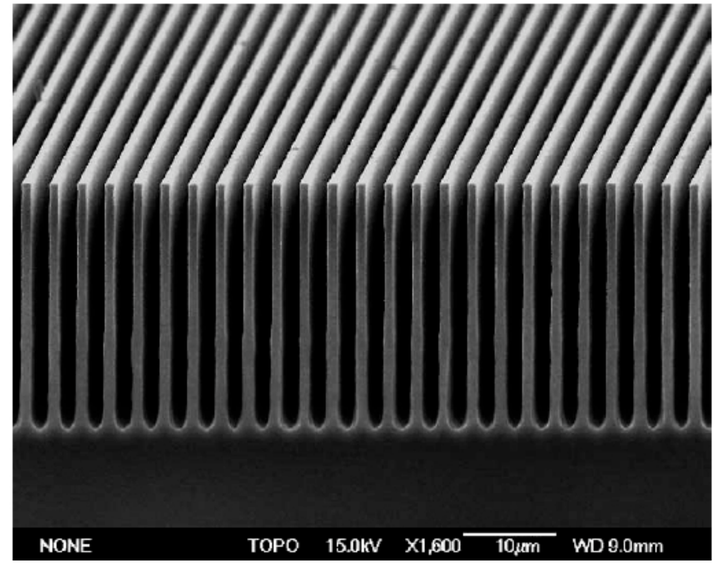
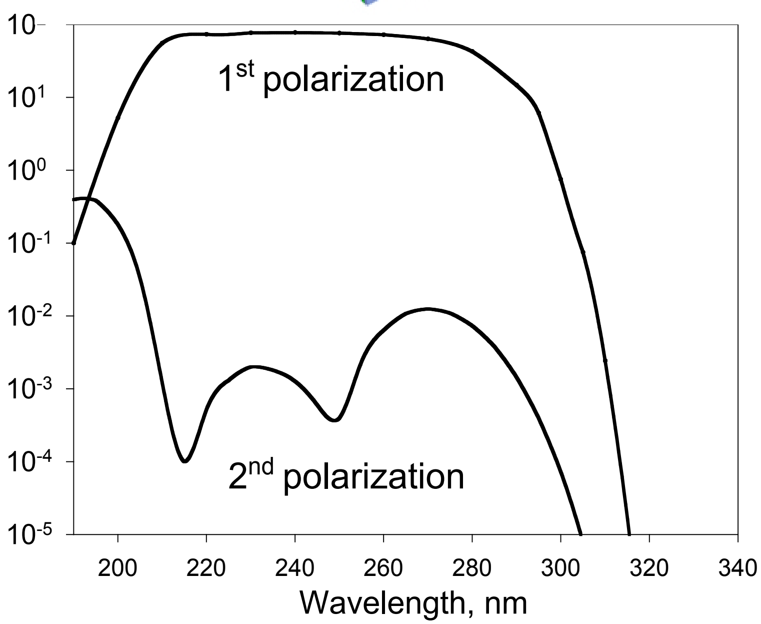
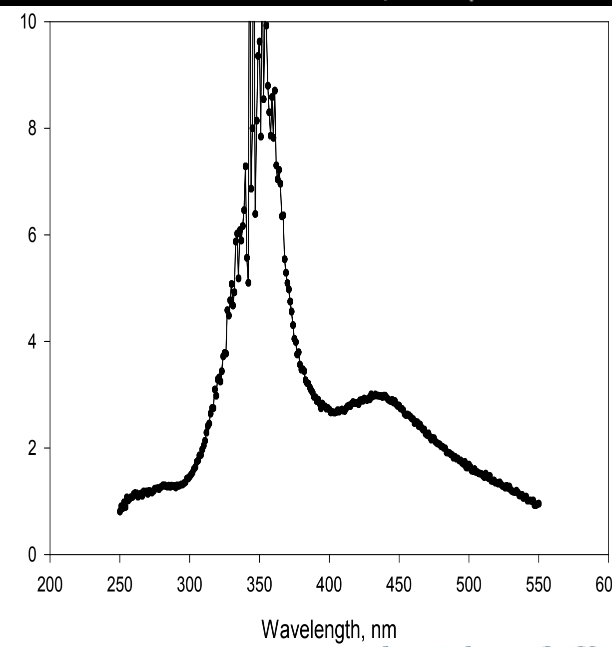
UV polarization components









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